

AUTOMATED CLASSIFICATION OF LANDFORMS IN TERRA CIMMERIA, MARS. B. D. Bue, *Dept. of Computer Science, Purdue University, 250 N. University St., West Lafayette, IN 47907, USA, (bbue@cs.purdue.edu)*, T. F. Stepinski, *Lunar and Planetary Institute, Houston TX 77058-1113, USA, (tom@lpi.usra.edu)*.

Abstract. We present an automated method for identification and characterization of landforms on Mars using digital topography data. Applying our algorithm to the Terra Cimmeria region yields 20 distinct landforms whose spatial distribution is shown using a thematic map of landforms. Such a map serves as the first approximation to a geomorphic map of the site. We discuss future application of our method including automated crater counting and characterization.

Introduction. Automated, fast, and objective description of Martian landforms would alleviate the tedious task of photo-geologic interpretation and significantly speed up production of geomorphic and geologic maps. To this end, we have developed an automated method for classification and characterization of Martian topographic features. It is "an unsupervised" algorithm, meaning that we do not impose any structure onto the classification, instead the classification "emerges" from the data allowing for a potential discovery of novel structures. Central to our approach is the concept of a digital topography model (DTM), an organization of topographical information that enables automated classification and statistical analysis of landforms on Mars. The DTM is somewhat analogous to the concept of a multispectral image, but it pertains to topographical rather than imagery data. Pixels in the DTM carry an array of local and regional topographical information that allows assigning landform-based semantic labels to individual pixels. The results are visualized by means of a thematic map of landforms. The landforms are characterized and compared via statistical analysis of their constituent pixels. To demonstrate the capabilities of our method, we automatically classified landforms in the Terra Cimmeria region of Mars. This site was previously studied thoroughly by Irwin and Howard [1].

Methods. Our technique uses the concept of a DTM introduced and described in detail in [2]. In the DTM each pixel carries a vector of numerical topographic attributes. Six such attributes are used in this study. They are: elevation, "flood", slope, flooded slope, contributing area, and flooded contributing area. In order to identify craters and other basins we artificially modify the original elevation field using the so-called "flooding" algorithm. It identifies all enclosed depressions and raises their elevation to the level of the lowest pour point around their edges, thus producing a flooded elevation field. We refer to the difference between flooded and original elevation fields as the "flood." The contributing area of a pixel is the total number of other pixels that can be linked to it through an uninterrupted chain of slope directions. In landscapes experiencing rainfall, it measures concentration of flow and identifies ridges and channels.

We perform an unsupervised classification of all pixels in the DTM based on similarity (in the sense of Euclidian metric) of their topographic attributes vectors. The output is the set of mutually exclusive and exhaustive classes of pixels that can be associated with specific landforms. To obtain these

classes we cluster the pixels using a two-level approach consisting of self-organizing map (SOM) and Ward's minimum variance grouping methods. The SOM [3] is a neural network technique that, through an iterative procedure, groups similar vectors into nearby points on a 2-D grid composed of nodes. In the first step, all pixels ($\sim 10^8$) are mapped using the SOM into grid's nodes ($10^2 - 10^3$) in such a way that very similar pixels are associated with the same node. Thus, a set of pixels mapped to a given node are well characterized by just a single, "representative" attribute-vector calculated by averaging all vectors mapped to that node. The SOM assures that representative vectors of neighboring nodes are similar. In the second step, we cluster SOM-produced representative vectors ($10^2 - 10^3$) into assigned number of classes ($\sim 10^1$) using Ward's hierarchical clustering method [4]. As a result pixels in a given class have similar topographic attributes and are expected to constitute a specific landform.

For the Terra Cimmeria site the elevation field was obtained from MEGDR digital topography data with resolution of 128 pixels/degree. This site (coordinate bounds are 124.25° E, 136° E, 30.75° S, and 0° N) is located mostly on the Noachian highlands, but a dichotomy boundary passes through its NE corner. There are 5,303,888 pixels in the DTM that we have classified into 20 individual classes, labeled 1 to 20. Landform interpretations were assigned to each class on the basis of statistical analysis of class pixels' attributes and their spatial distribution.

Results. Fig. 1 shows the thematic map of landforms in Terra Cimmeria generated using our method. We have divided the 20 classes into 5 groups: "highlands", "craters", "lowlands", "high relief", and "channels". A group's alias broadly describes a type of landform associated with the pixels in that group. The classes within a group represent a finer subdivision of landforms. Of particular interest, our classifier has recognized the dichotomy between the terrain north and south of the escarpment and has assigned terrain north of the escarpment to four unique classes which we have grouped as the lowlands. The escarpment itself has been classified as a separate class (14) and grouped with three other classes (18, 20, and 16) as the high relief terrain. Class 18 is the ejecta on the outsides of the craters and classes 20 and 16 are crater rims. Five classes represent a terrain inside craters and other basins, they are grouped as craters. Finally, six classes represent inter-crater plateau in the Noachian highlands. These are grouped as highlands and differ mostly by the value of elevation.

Conclusions and Discussion. Our automated classification of DTM pixels with respect to their local topographic attributes results in classes that have high spatial integrity and thus correspond to recognizable landforms. Using our method we have produced a thematic map of landforms for the Terra Cimmeria region of Mars that may serve as the first approximation to a geomorphic map. We stress that landforms appearing

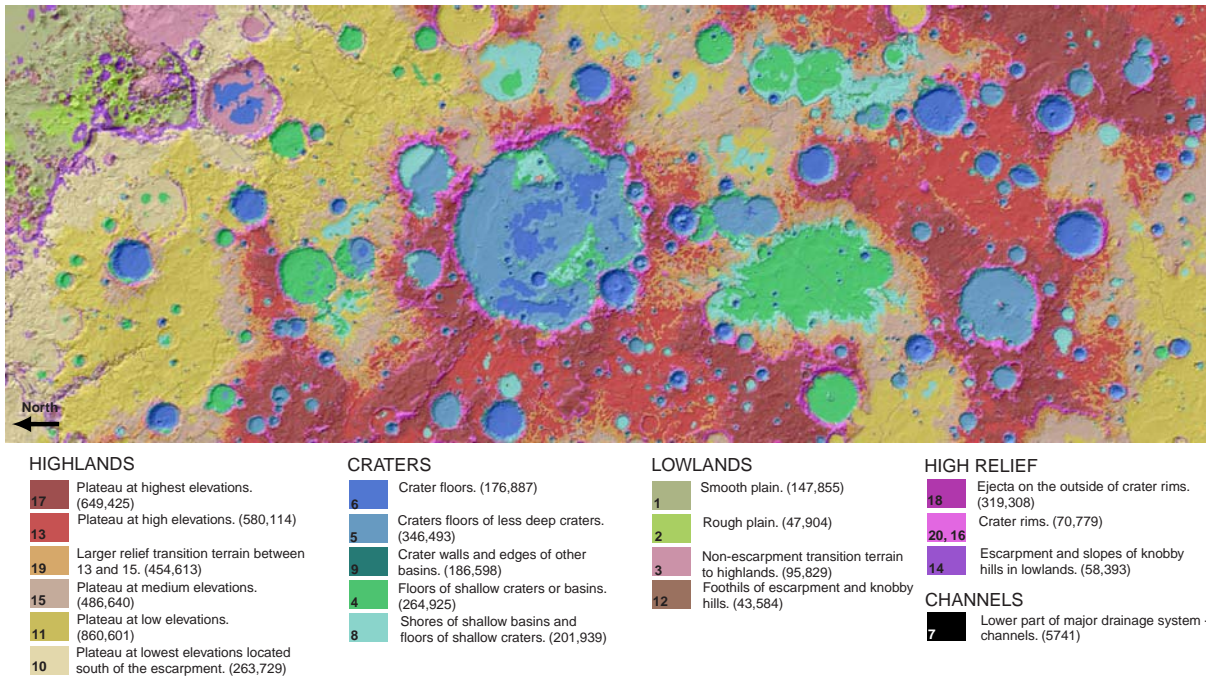


Figure 1: Thematic map of landforms for the Terra Cimmeria site overlaid on the shaded relief. The legend ascribes landform interpretation to the classes. The numbers indicate class label. The numbers in brackets represent number of pixels in a class. Note that a reproduction of the map in this paper does not have sufficient resolution to show all pixels.

on the map were not predetermined, instead they emerged from the site's topographic data. Different landforms may be identified if our method is applied to a different site. A thematic map exhibits information in a style that differs from more familiar presentations like, for example, a topographic map. Visually, a thematic map appears simpler and easier to interpret than a topographic map because it offers a pre-processed information. Many interesting topographic features, such as, for example, a leaf-shaped basin to the right of Herschel crater, stand out in the thematic map. We have also found an interesting property of the inter-crater plateau. The highest plateau (classes 17 and 13) and the lowest plateau (classes 15, 11, and 10) are quite flat, but a transition between the two is, on average, more steep (class 19).

Future applications of our method will include an automated crater counting and characterization. For the Terra Cimmeria site our algorithm has found 2326 crater candidates. Total of 891 of them have diameter > 2 km. For comparison, manual counting [1] have found 890 such craters. A near-perfect agreement in the total number of craters is probably a coincident, nevertheless, we are confident that with future development our algorithm will reliably count craters. Another future application is identification of partially filled craters, and craters with breached walls. Such craters may be rem-

nants of ancient lakes and are objects that deserves detailed studies. Candidates for such craters stand out in our map as craters with floors classified as class 5 or 4 instead of class 8 as expected for the majority of unaltered craters.

Addition of further topographic attributes may increase the precision of an automated classification of landforms. In particular we investigate the following attributes defined at-the-pixel: regional surface roughness, regional coherence of slope directions, and hillslope-to-valley length (see [1] for details). In addition to increasing the precision of classification, an extended set of topographic attributes may result in identification of new landforms, that did not stand-out in the classification based on the presently used attributes.

References

- (1). R. P. Irwin III and A. D. Howard., 2002, Drainage Basin Evolution in Noachian Terra Cimmeria, Mars, *Journal of Geophysical Research*, vol 107, No. E7 pp. 10-1 - 10-23
- (2). T. Stepinski and R. Vilalta, 2005, Digital Topography Models for Martian Surfaces, *IEEE Geoscience and Remote Sensing Letters*, (in print).
- (3). T. Kohonen, 1995, *Self-organizing maps*, Springer, Berlin.
- (4). J. H. Ward, Jr., 1963, Hierarchical Grouping to Optimize an Objective Function, *Journal of the American Statistical Association*, vol. 58, issue 301.